Dark Photons at LHCb

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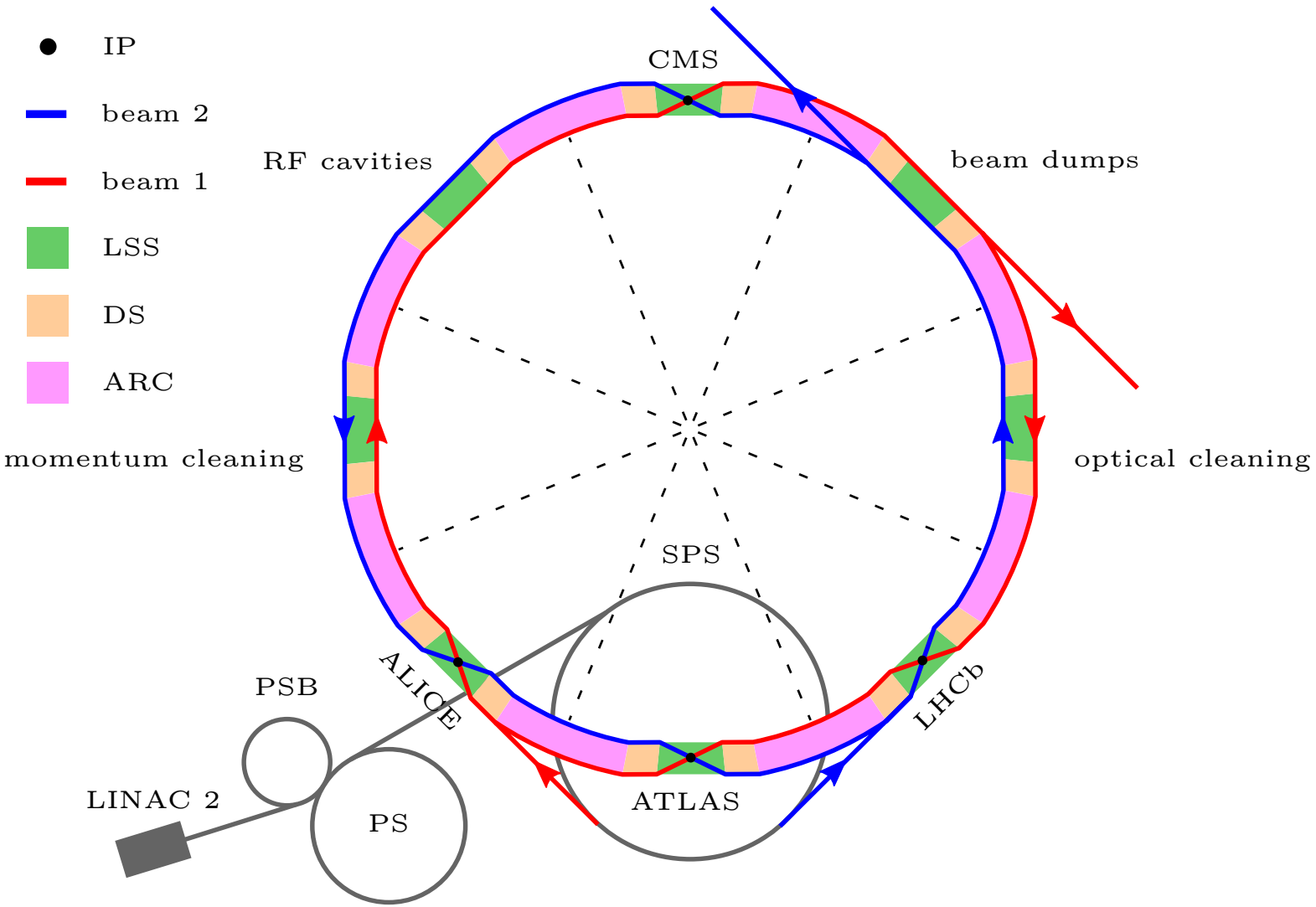
Overview

- LHCb
- dark photons
- dark photon searches

- high luminosity collider
- **excellent signal/background separation**
- **low mass and p_T data acquisition**
  $\rightarrow$ LHCb!

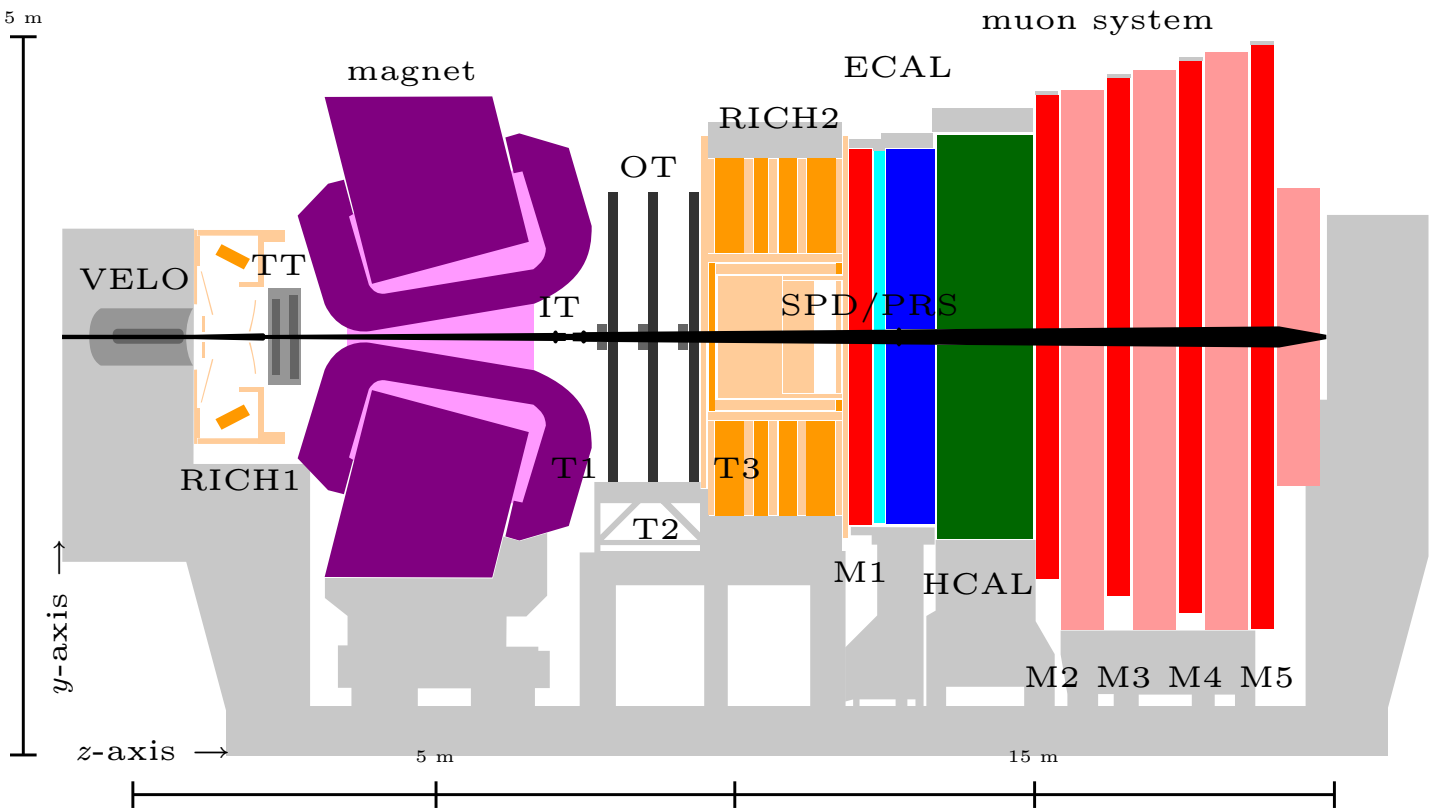
LHCb

Large Hadron Collider



Detector

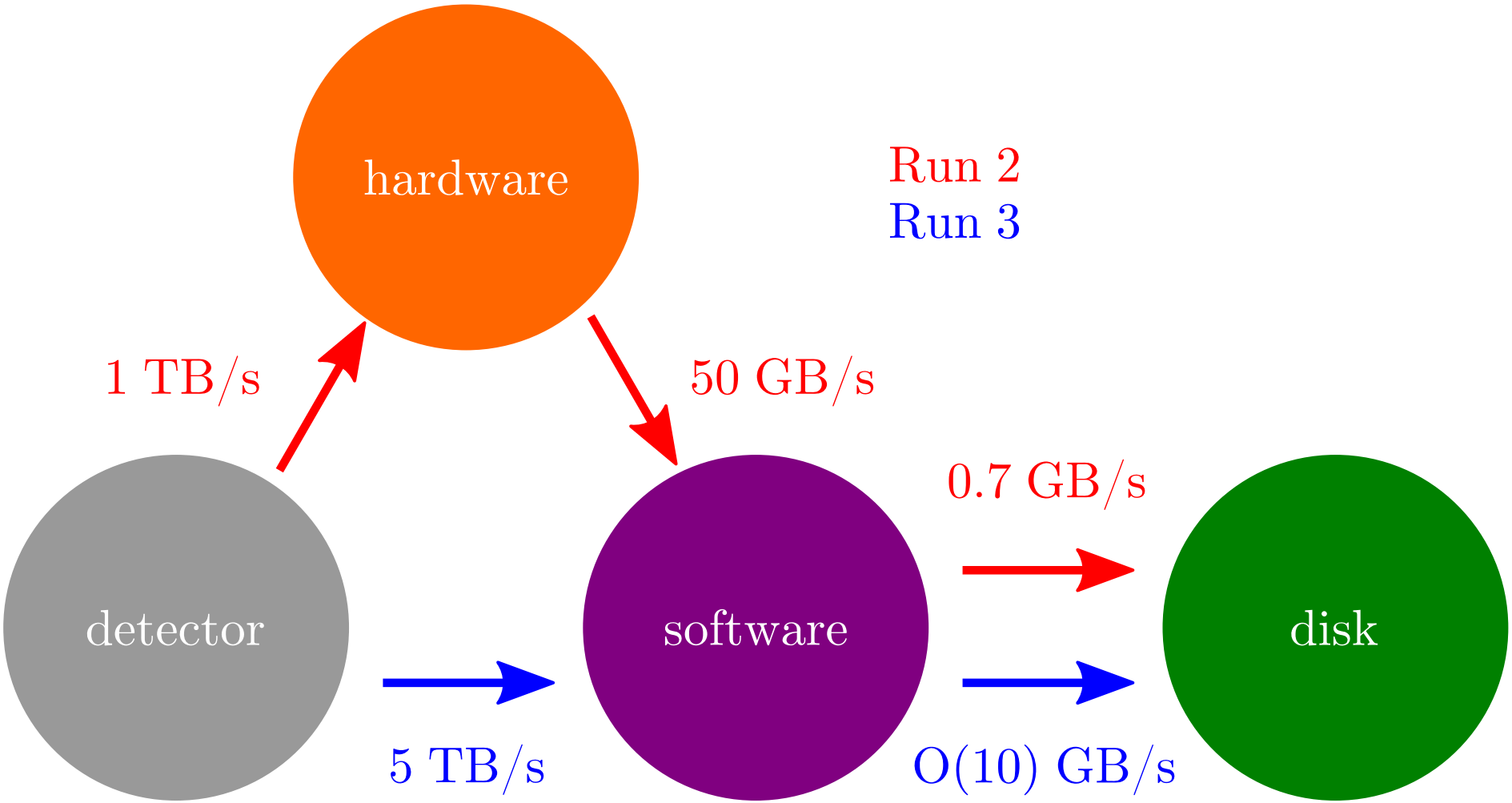
LHCb, IJMPA **30** (2015)



- fully instrumented between $2 < \eta < 5$
- momentum resolution between 0.5% at 5 GeV to 1% at 200 GeV
- impact parameter resolution of $13 - 20$ μm for tracks
- secondary vertex precision of $0.01 - 0.05(0.1 - 0.3)$ mm in $xy(z)$

Trigger

LHCb, JINST 8 (2013) P04022



Datasets

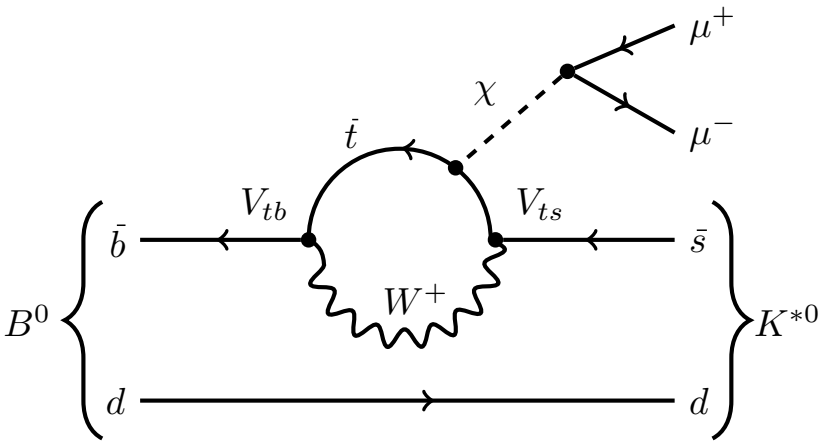
- projected luminosity per run

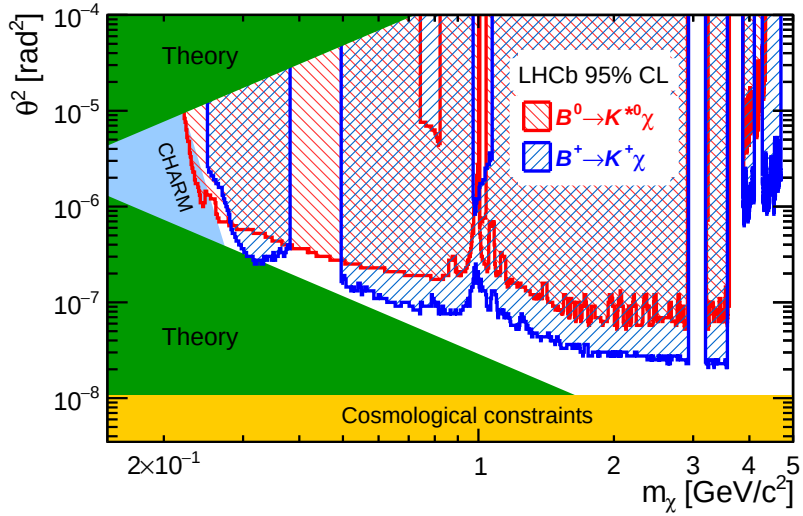
LHC era				HL-LHC era	
Run 1(a) 2011	Run 1(b) 2012	Run 2 2015 - 2019	Run 3 2021 - 2023	Run 4 2027 - 2029	Run 5 2031 - ?
1 fb^{-1}	2 fb^{-1}	5 fb^{-1}	15 fb^{-1}	23 fb^{-1}	300 fb^{-1}?

- heavy ion and **fixed target** data
- LHCb upgrade during LS 2
  - LHCb-PUB-2014-040
  - replacement of readouts and photo-detectors for the RICHs
  - replacement of tracking detectors
  - **full software trigger**, see LHCb-TDR-016
    - currently limited by hardware readout at 1 MHz
    - upgrade will read out entire detector at 40 MHz

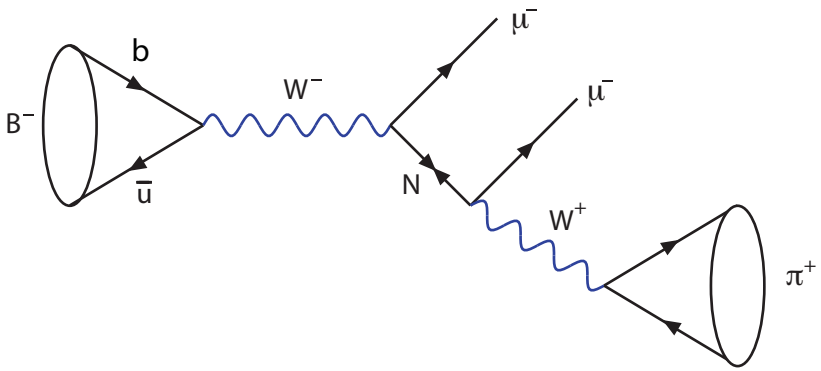
Published Searches

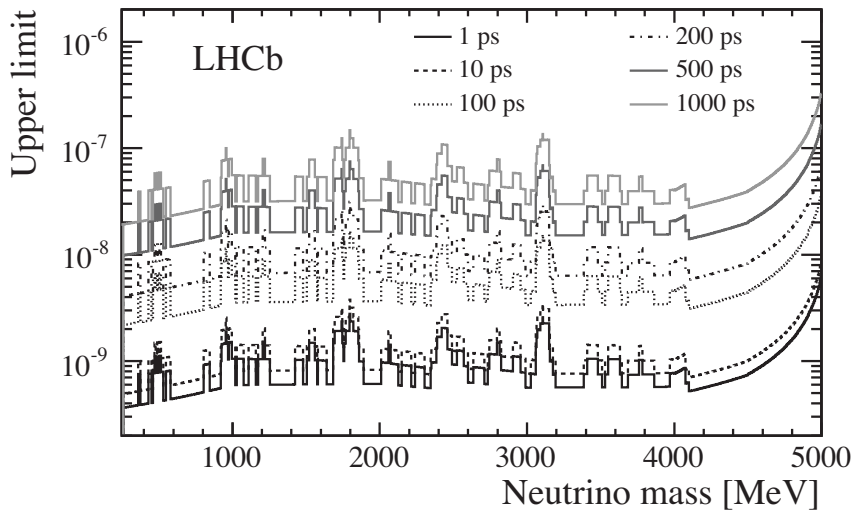
PRL 115 (2015)
LHCB-PAPER-2016-052





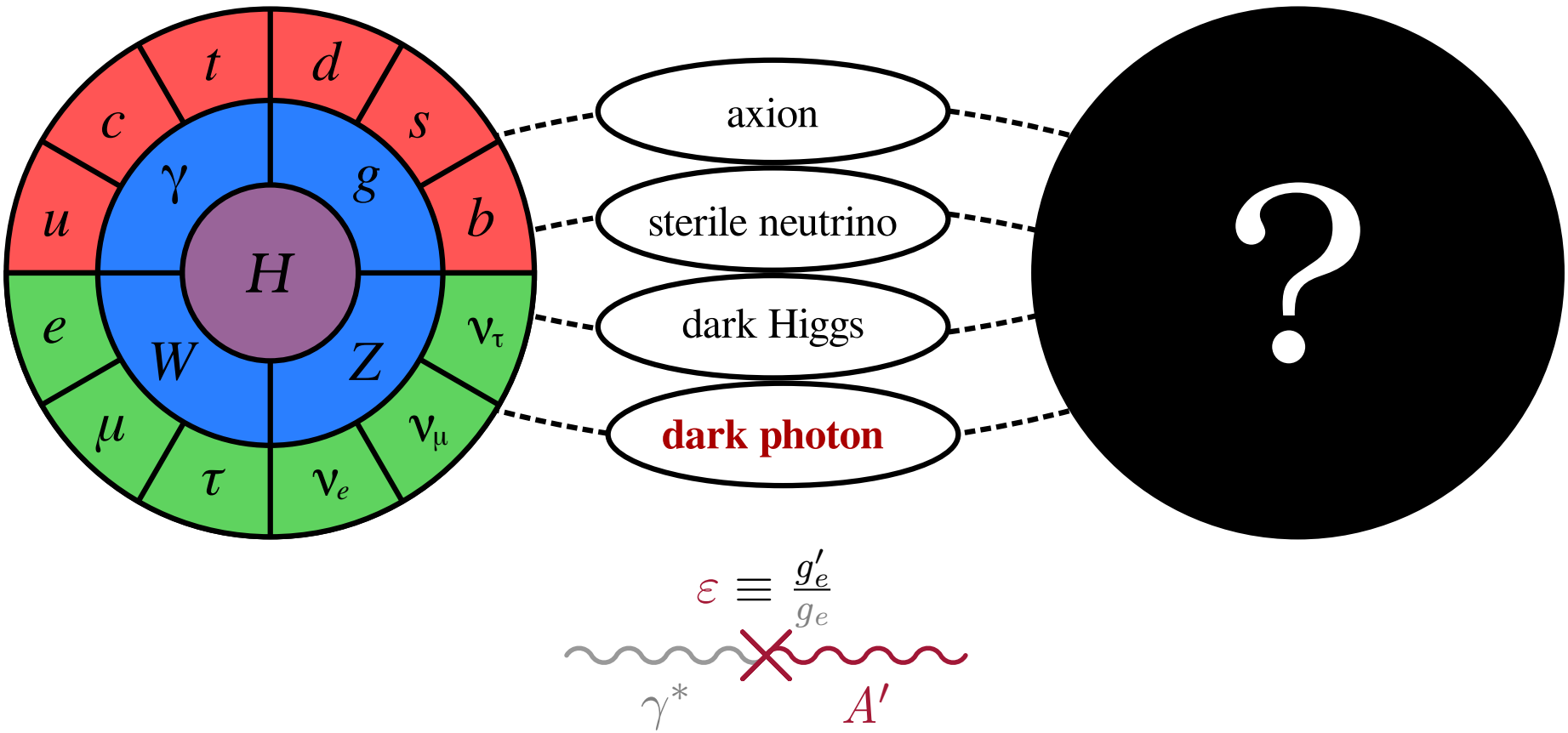
PRL 112 (2014)





Dark Photons

Hidden Sector



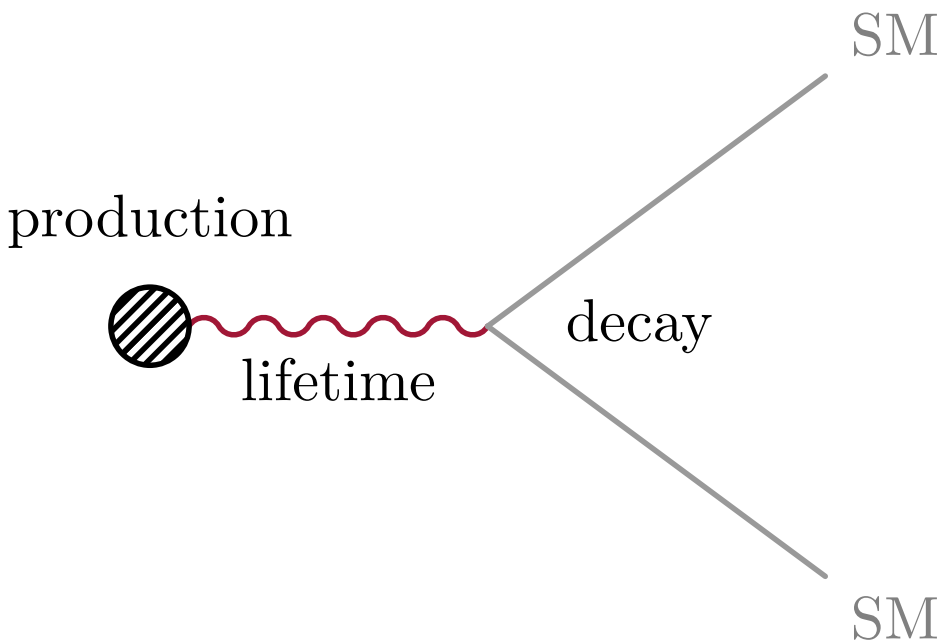
Properties

1. production
   - electron-positron annihilation
   - hadron decays
   - electron scattering
2. lifetime
   - *prompt* or *displaced*

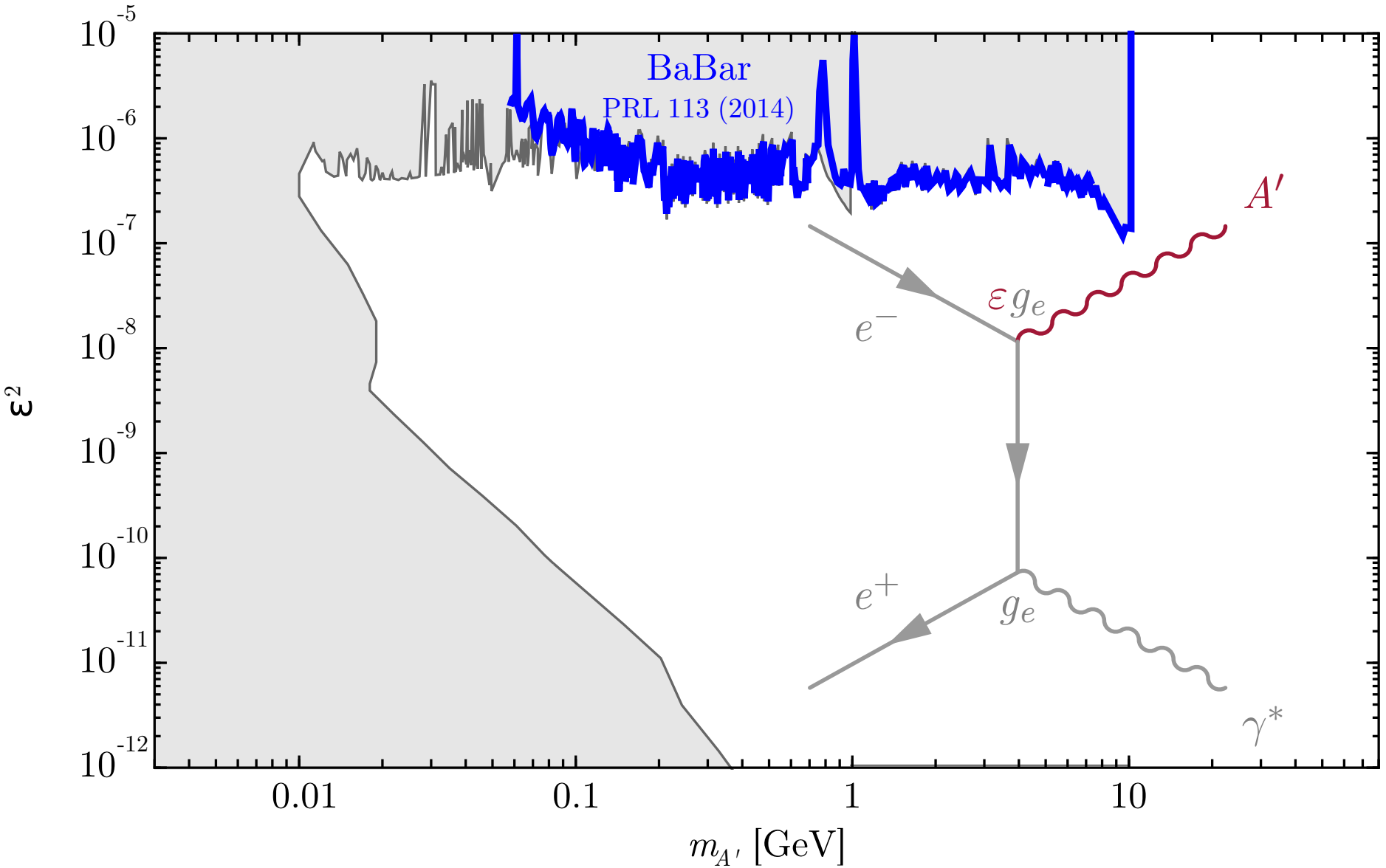
$$\tau(\varepsilon, m_{A'}) = \frac{\hbar}{\Gamma_{A'}(\varepsilon, m_{A'})}$$

3. decay

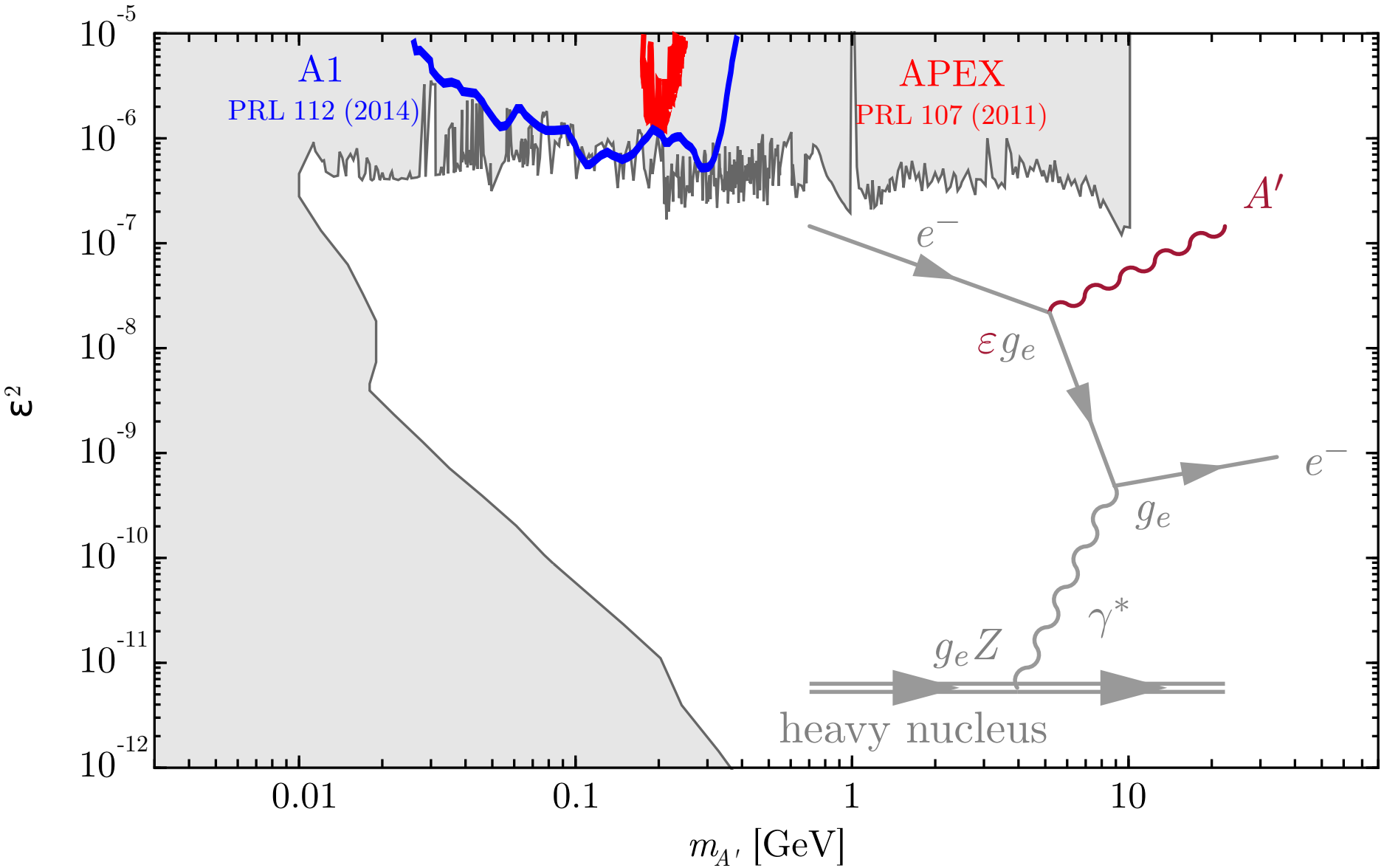
$$\mathrm{BR}_{A' \to X}(m_{A'}) = \frac{\Gamma(\varepsilon, m_{A'})_{A' \to X}}{\Gamma_{A'}(\varepsilon, m_{A'})}$$



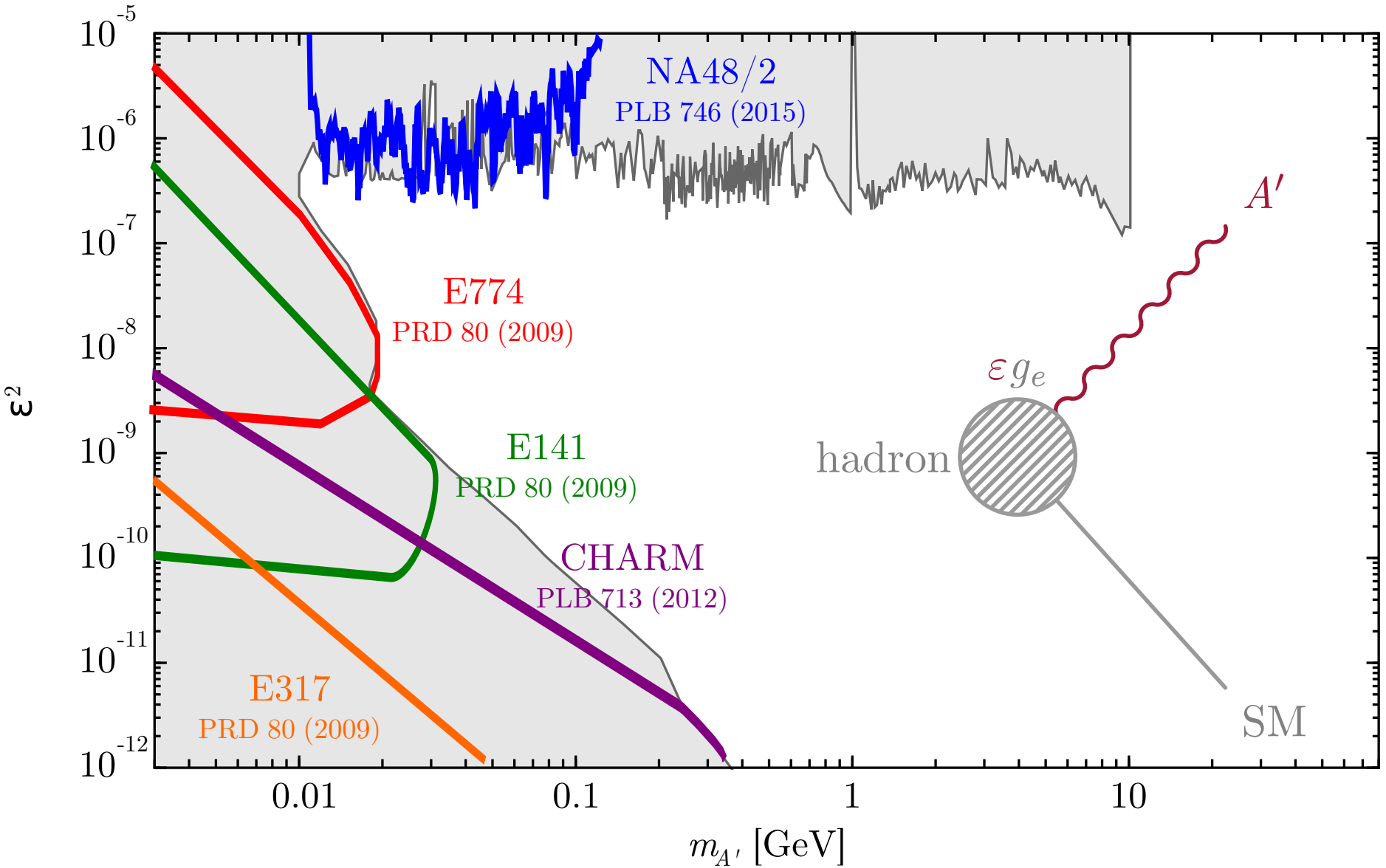
Production: Electron-Positron Annihilation



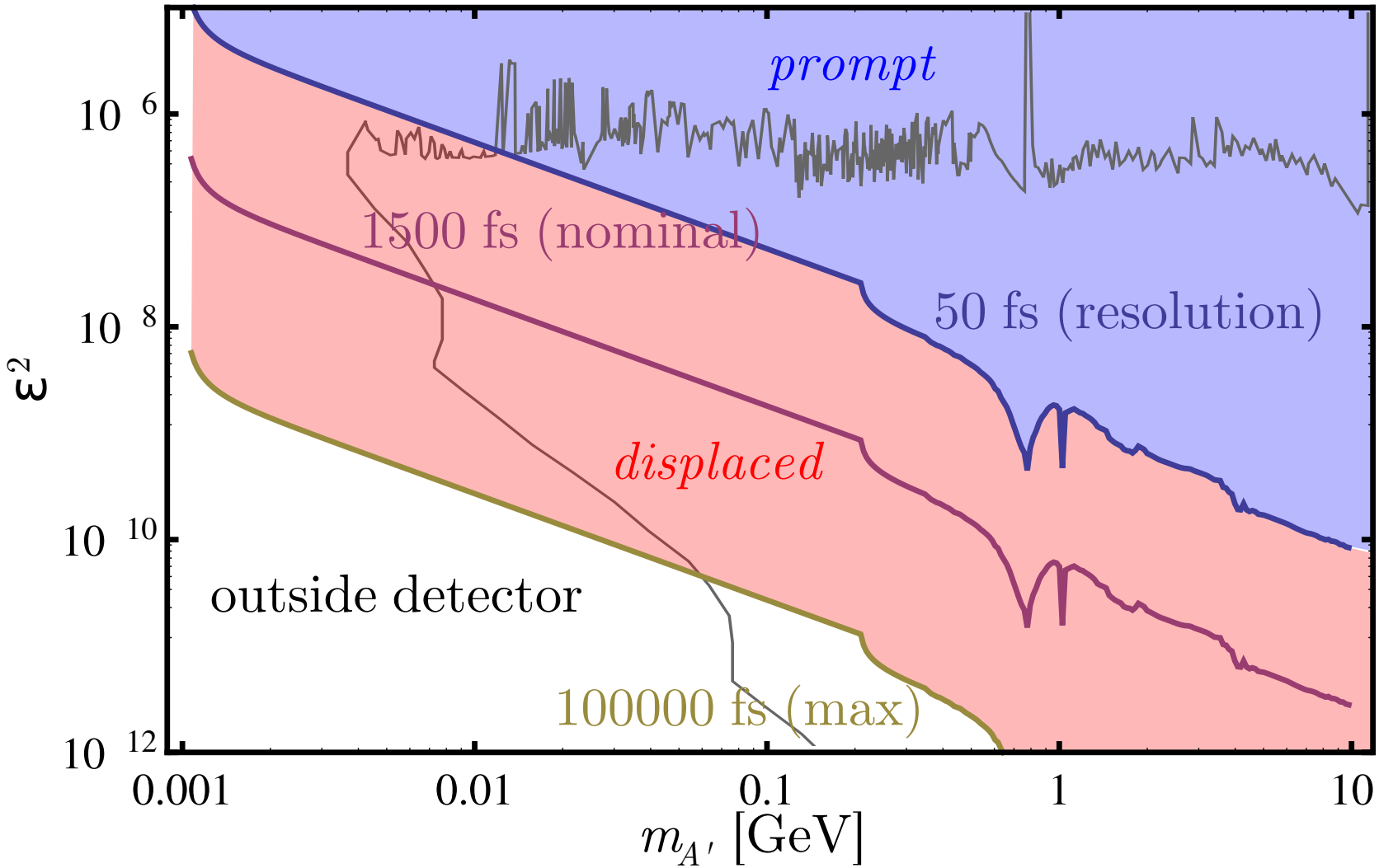
Production: Electron Scattering



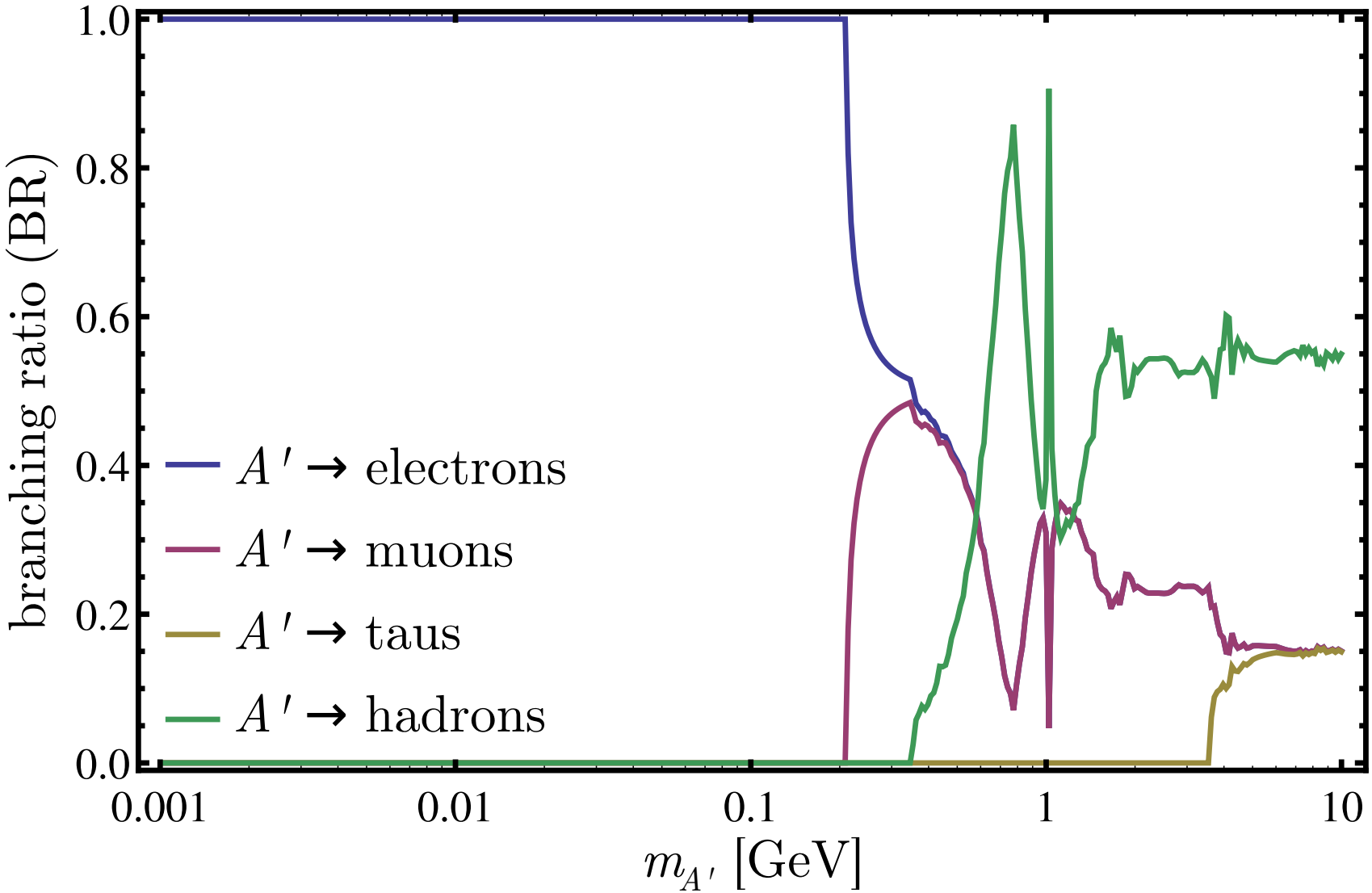
Production: Hadron Decays



Lifetime


prompt
1500 fs (nominal)
50 fs (resolution)
displaced
outside detector
100000 fs (max)
ϵ^2
10^{-6}
10^{-8}
10^{-10}
10^{-12}
0.001
0.01
0.1
1
10
$m_{A'}$ [GeV]

Decay


1.0
0.8
0.6
0.4
0.2
0.0
branching ratio (BR)
$A' \to$ electrons
$A' \to$ muons
$A' \to$ taus
$A' \to$ hadrons
0.001
0.01
0.1
1
10
$m_{A'}$ [GeV]

Future Dark Photon Searches

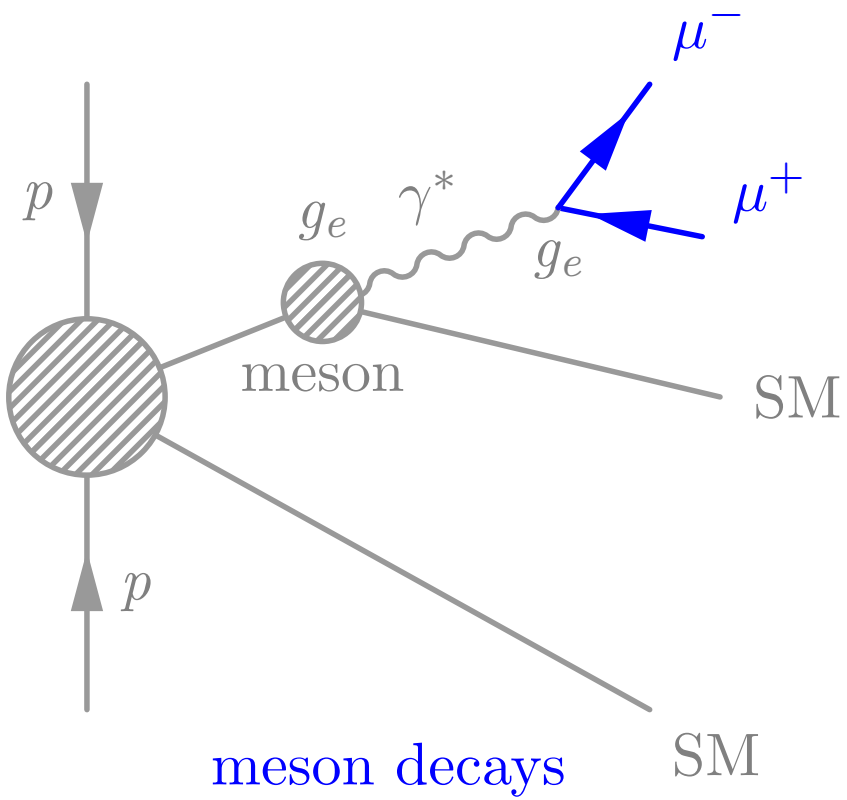
inclusive $A'[\mu\mu]$

PRL 116 (2016): PI, Soreq, Thaler, Williams, Xue

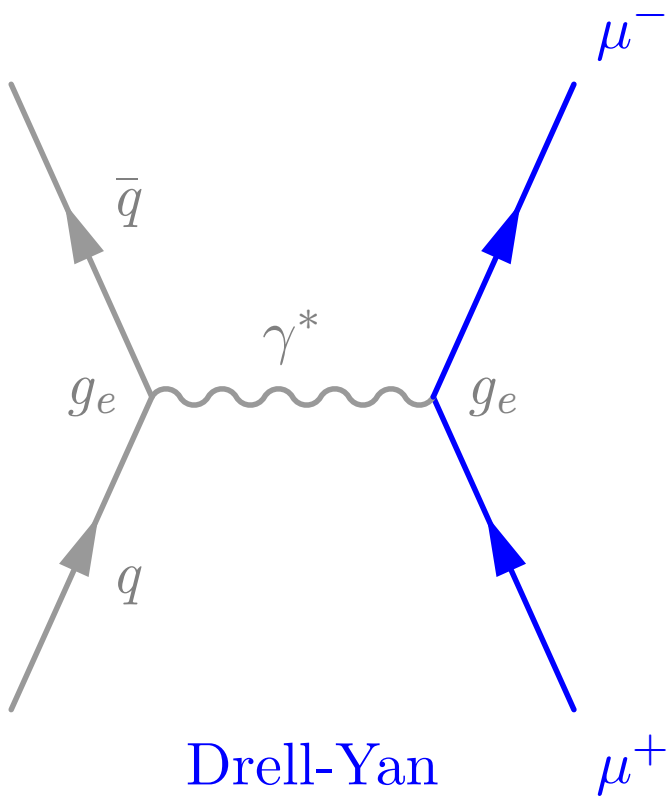
$D^{*0} \to D^0 A'[ee]$

PRD 92 (2015): PI, Thaler, Williams, Xue

Good Backgrounds (*prompt*)

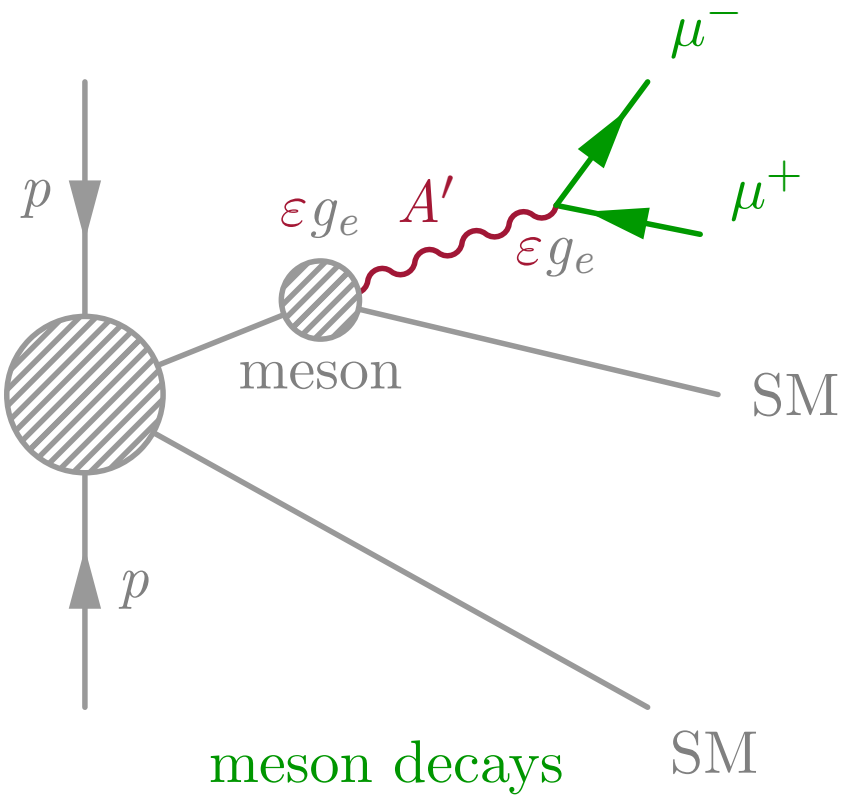


meson decays

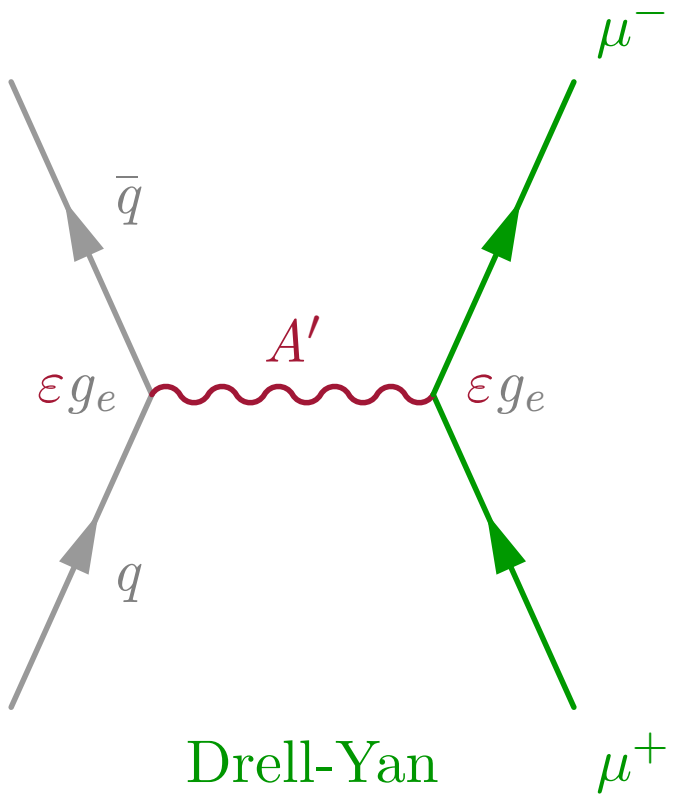


Drell-Yan

Signal (*prompt* and *displaced*)



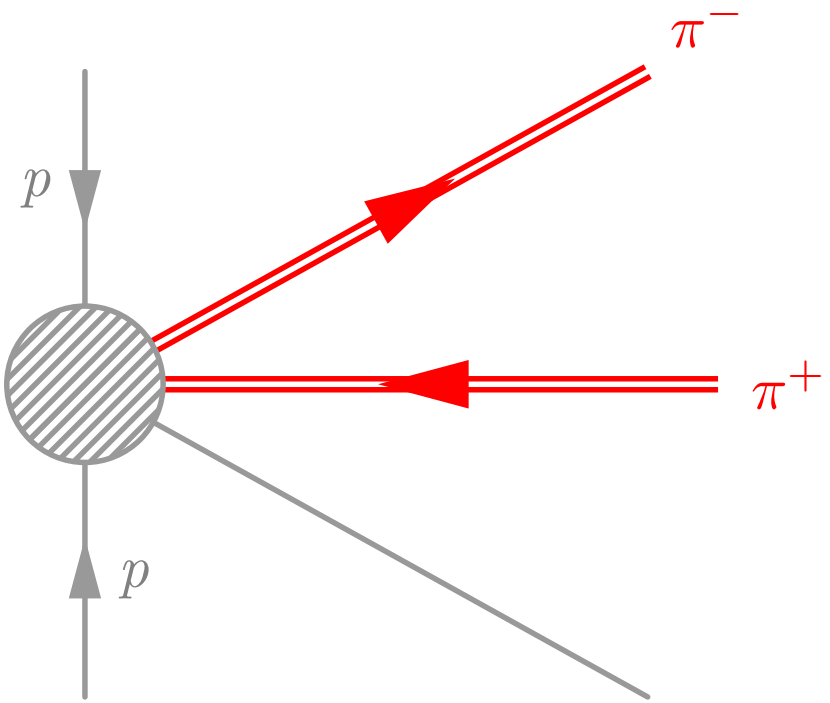
meson decays



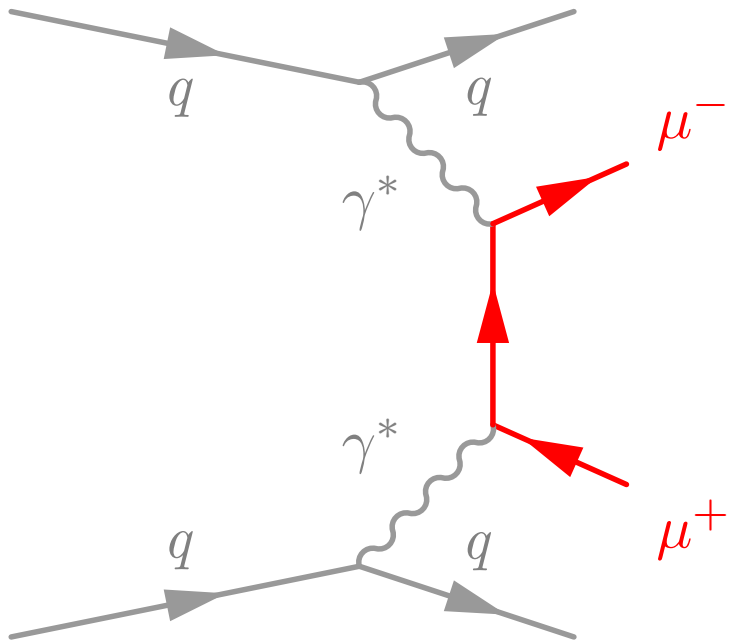
Drell-Yan

$$N_{\text{signal}} \approx \frac{\pi \varepsilon^4 m_{A'}^2}{8\Gamma_{A'}(\varepsilon, m_{A'})\delta_m} N_{\text{good}} \text{ per } 4\delta_m, \quad \delta_m \approx 0.4\% m$$

Bad Backgrounds (*prompt*)



mis-ID (π as μ) SM

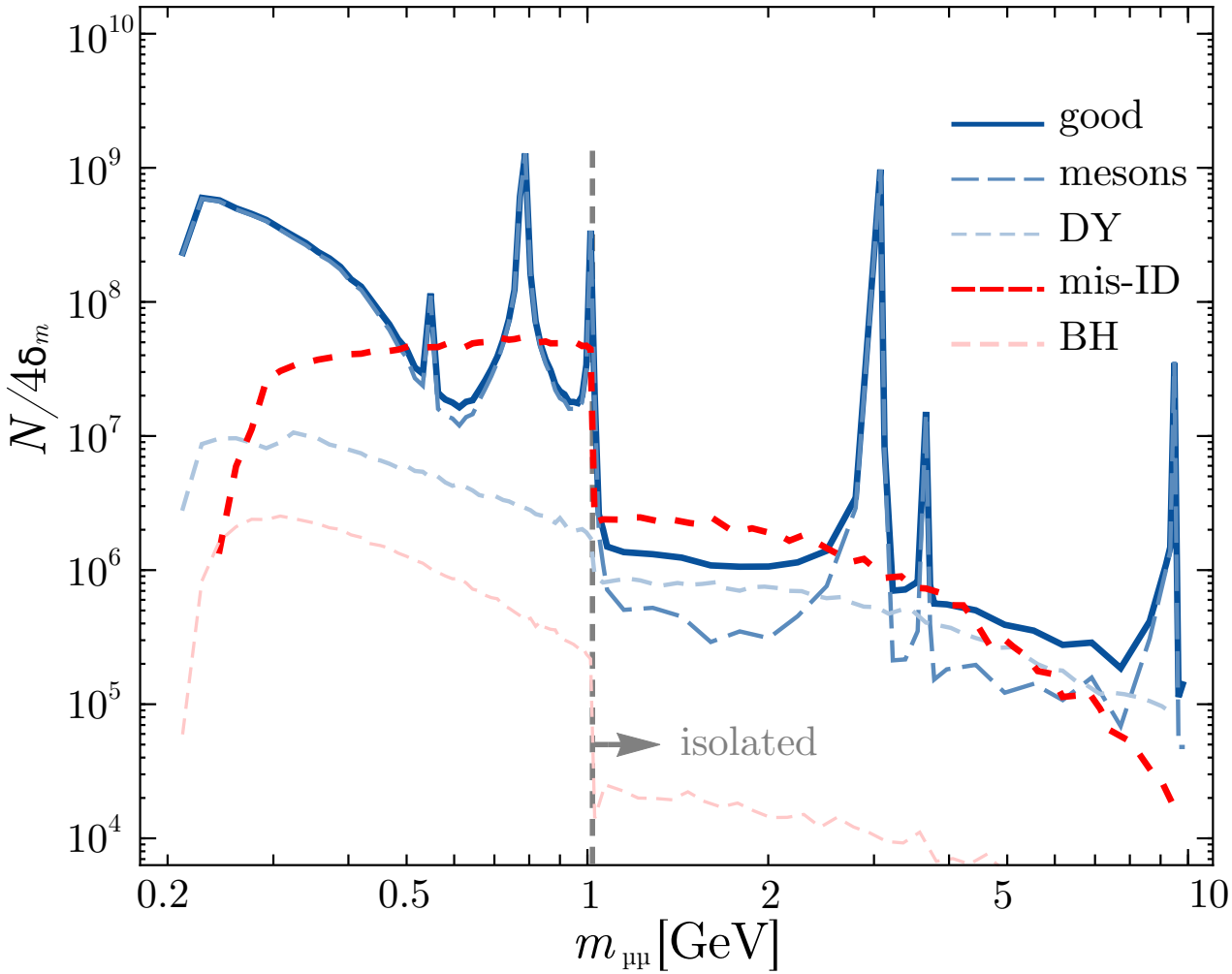


Bethe-Heitler

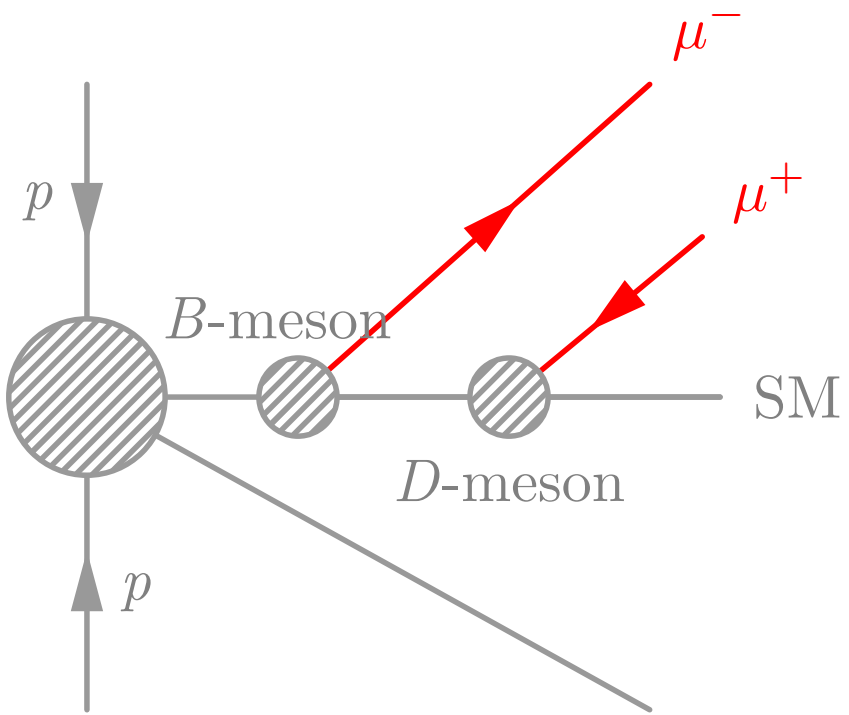
N_{signal} is not proportional to N_{bad}

LHCb mis-ID probability $\approx$ 1 out of 1000

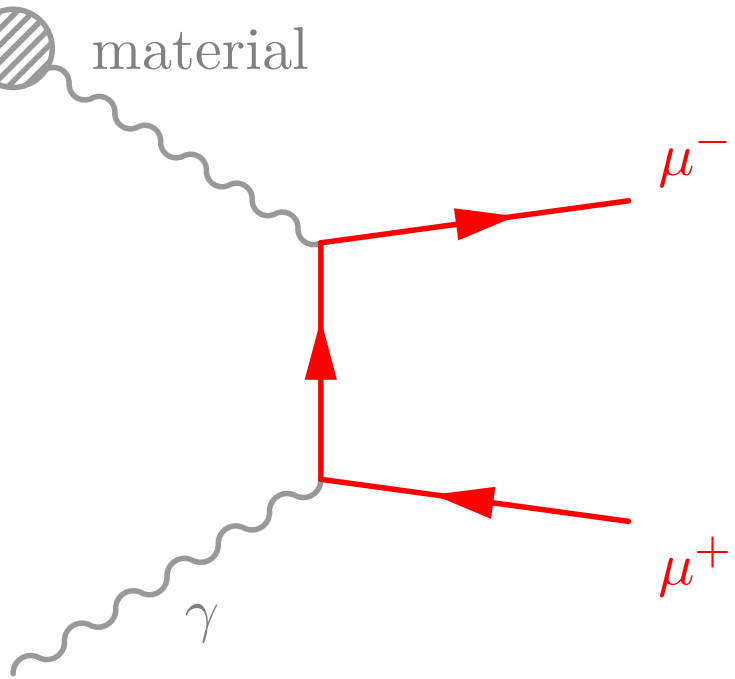
Prompt Production



Bad Backgrounds (*displaced*)



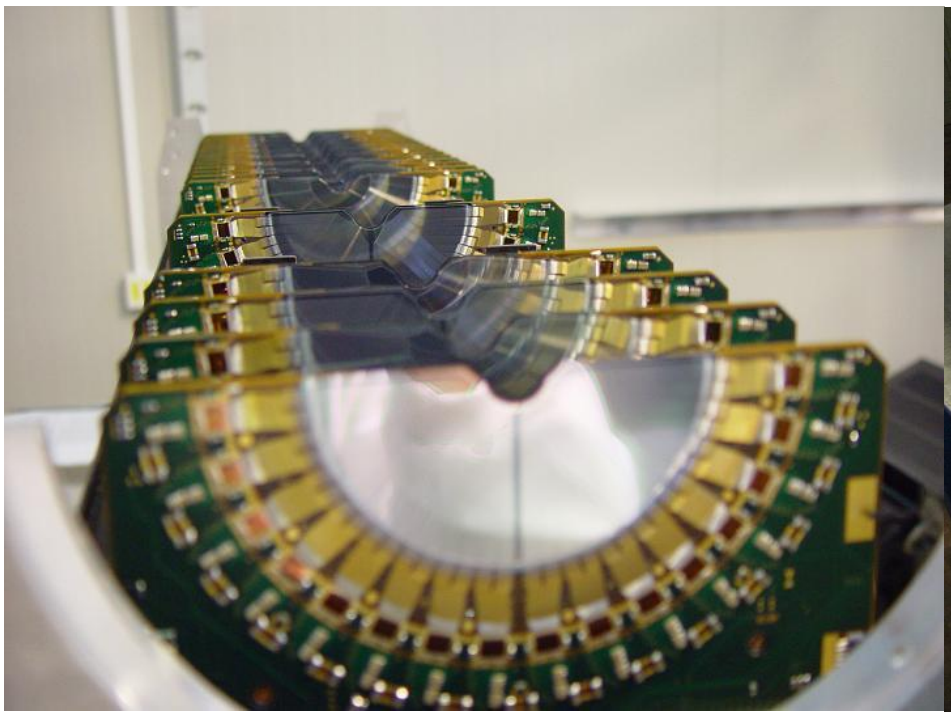
heavy flavor

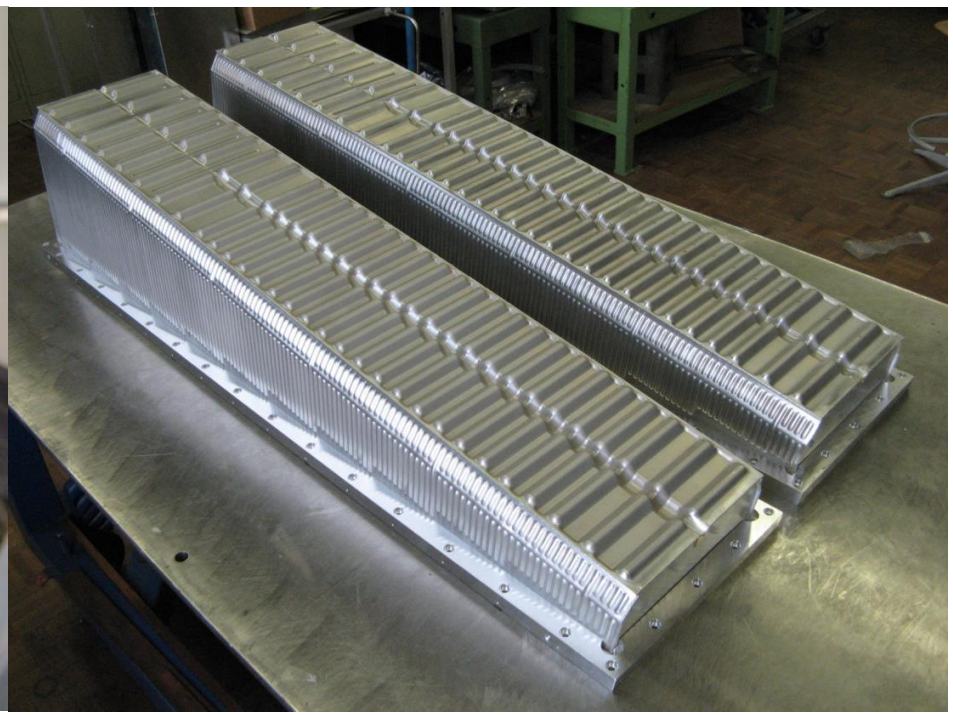


material interactions

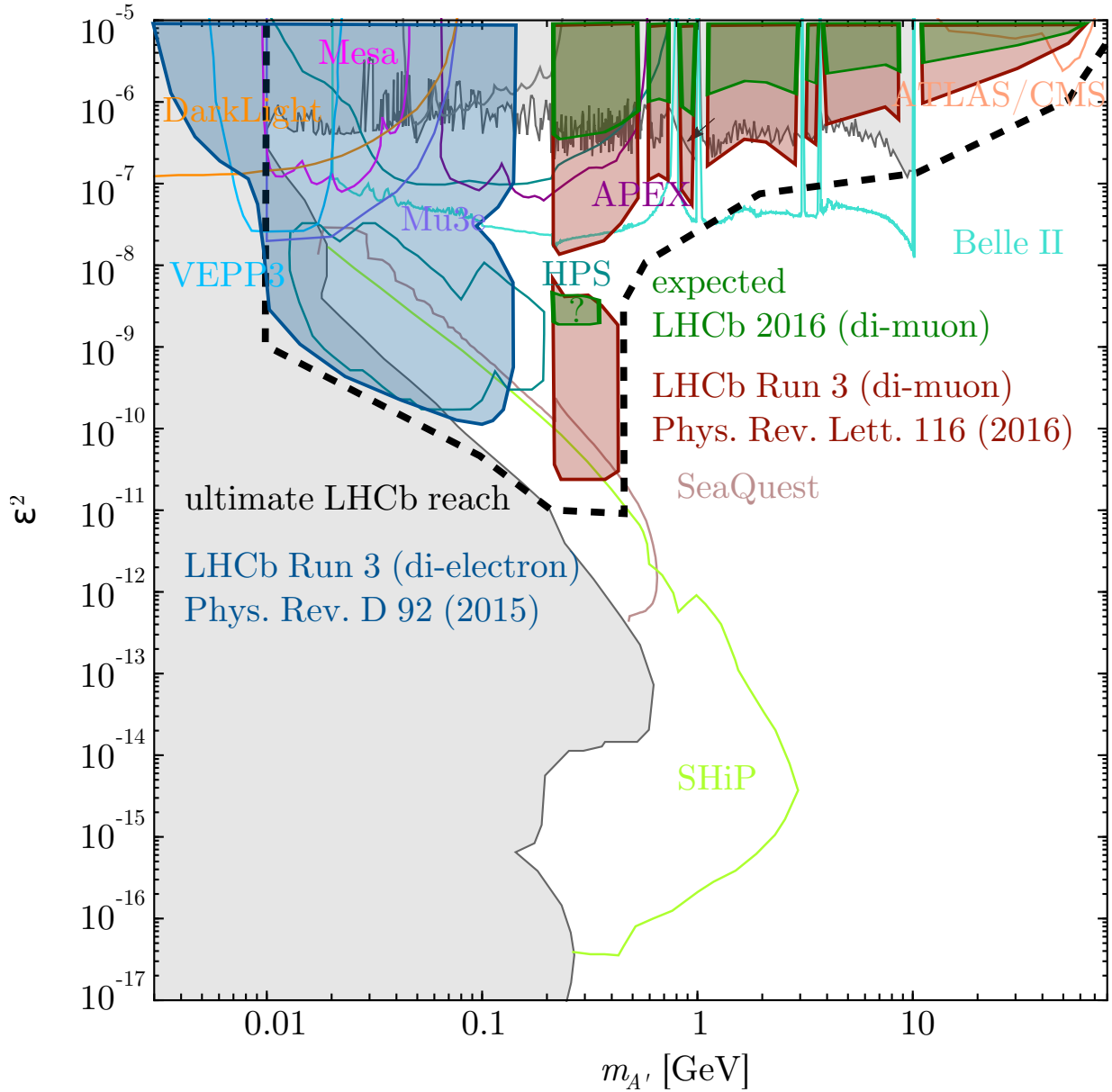
$N_{\text{heavy}} \approx 10000$ per $4\delta_m$

Material



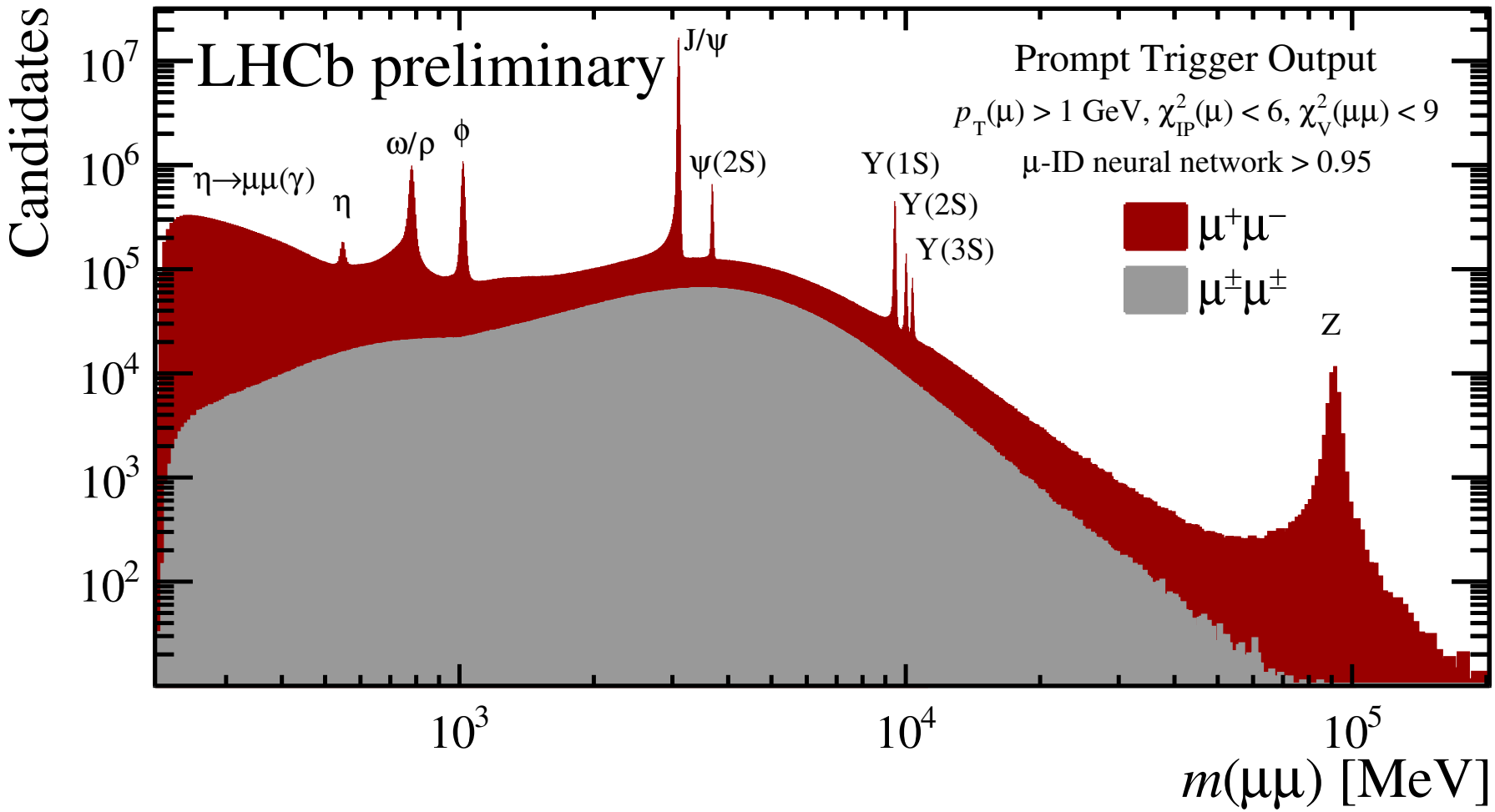


Full Reach


Mesa
DarkLight
ATLAS/CMS
APEX
Mu3e
Belle II
VEPP3
HPS
?
expected
LHCb 2016 (di-muon)
LHCb Run 3 (di-muon)
Phys. Rev. Lett. 116 (2016)
SeaQuest
ultimate LHCb reach
LHCb Run 3 (di-electron)
Phys. Rev. D 92 (2015)
SHiP
ε^2
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{-14}
10^{-15}
10^{-16}
10^{-17}
0.01
0.1
1
10
$m_{A'}$ [GeV]

Conclusion

Real Data


LHCb preliminary
Prompt Trigger Output
$p_T(\mu) > 1$ GeV, $\chi^2_{IP}(\mu) < 6$, $\chi^2_V(\mu\mu) < 9$
μ-ID neural network > 0.95
$\mu^+\mu^-$
$\mu^\pm\mu^\pm$
Candidates
10^7
10^6
10^5
10^4
10^3
10^2
η→μμ(γ)
η
ω/ρ
φ
J/ψ
ψ(2S)
Υ(1S)
Υ(2S)
Υ(3S)
Z
10^3
10^4
10^5
$m(\mu\mu)$ [MeV]

Outlook

- inclusive $\mu\mu$ analysis underway
  - prompt data matches predictions
  - displaced backgrounds under control
  - expect projections to hold
- validation of $D^{*0} \to D^0 A'[ee]$ strategy
- phenonomelogy study to close gap between two strategies

Thank you!